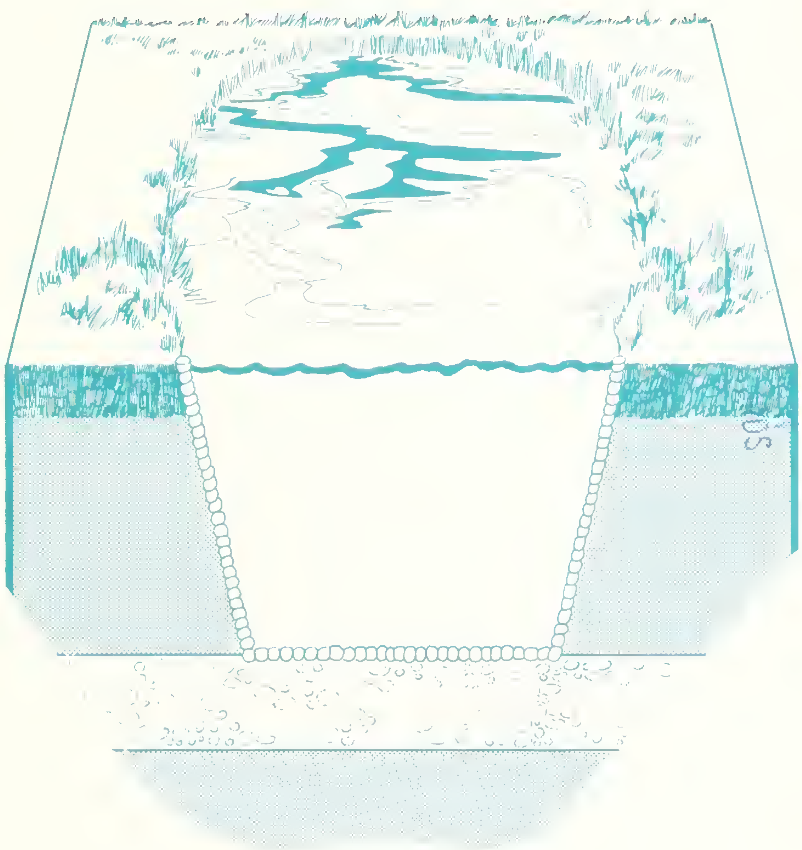
Operation and Design of Evapotranspiration Waste Disposal Systems

Victor R. Hasfurther and David H. Foster



Eisenhower Consortium for Western Environmental Forestry Research

ABSTRACT

Hasfurther, Victor R. and David H. Foster

1978. Operation and Design of Evapotranspiration Waste Disposal Systems. Eisenhower Consortium Bulletin 6, 21 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado. 80521.

An evapotranspiration unit for disposal of wastewater was constructed and operated at Laramie, Wyoming from August, 1973 to September, 1975. Results of the loading and wastewater treatment that occurred with the ET unit are presented. The results indicate that the use of evapotranspiration for treating wastewater from rural and mountain second homes during the warmer month of the year is feasible. The treatment of the wastewater by the ET unit through chemical and biological action is high and in many cases is within EPA standards for some uses of the water.

An ET unit can be sized using standard evapotranspiration equations and examples of sizing are given. The ET unit is cost competitive with conventional systems for individual home sites, provides zero ground and surface water pollution, and is readily adaptable to most rural and mountainous areas.

This report is dedicated to Erma Bombeck, whose astute observations of the world around her inspired the book, "The Grass is Always Greener Over the Septic Tank."

Eisenhower Consortium Bulletin 6 August 1978

OPERATION AND DESIGN OF EVAPOTRANSPIRATION WASTE DISPOSAL SYSTEMS

Victor R. Hasfurther

David H. Foster

Department of Civil and Architectural Engineering
College of Engineering
University of Wyoming

This research was supported by the Forest Service, U.S. Department of Agriculture, through the Eisenhower Consortium for Western Environmental Forestry Research.

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INTRODUCTION

Americans in recent years have time to spend in the pursuit of recreation and other leisure activities. This extra time has increased the demands for second home developments in attractive mountainous areas and along lake and reservoir areas. Rural areas are also increasing in population and housing density as people want to spend more time away from the congestion of the city. This growth of second and rural home developments has put a burden on lakes and streams in these areas because of the wastes being generated. In many of these areas, individual on-site waste disposal systems--such as a septic tank and leach field, or a package waste treatment unit--are being used to treat the wastes. For some remote second home areas, outdoor privies or direct discharge lines are not uncommon. As a result, waters are being rapidly degraded.

It is apparent that new technology is needed to solve this on-site waste treatment problem in areas where conventional systems have been found to be unsuitable. One system that has potential in this regard is an evapotranspiration waste disposal unit which confines the wastewater within the unit by an impermeable liner, and allows the water and wastes to escape only by evaporation, transpiration, and gases produced by treatment action within the unit.

Objectives

The basic purpose of this study of an evapotranspiration waste disposal unit (ET unit) near Laramie, Wyoming was to determine its effectiveness as a means of wastewater disposal. One goal was to determine how the quantity of wastewater evapotranspirated was influenced by the time of year and size of unit. Studies were also conducted to help determine the wastewater treatment capability of the unit in case of overflow and for health hazard reasons. In addition, this permitted an estimation of the rate of destruction of degradable pollutants as well as the build up rate of nondegradable materials such as salts.

The study had the following as primary objectives:

1. Design, construct, test, and evaluate the performance of an ET unit for waste disposal intended for individual family dwellings.

2. Develop a method for sizing an ET unit for different locations and loading rates.

3. Compare the costs of an ET unit with conventional units (septic tank and leach field and package treatment plants).

Literature Review

Goldstein (1973) estimated that in the United States some 30 percent of the population depends on septic tank and cesspool installations, outmoded privies or direct discharge to water sources for treatment or disposal of wastes. Miller (1974) and Schmidt (1974) have shown that a major drawback to these conventional methods of waste treatment is that the liquid which seeps from the privy or leach field is frequently highly polluted, and could contaminate a significant portion of the surrounding groundwater systems. Peavy and Groves (1977) found that septic tank drainfields in which the groundwater was near the surface caused nitrate contamination of the groundwater in the area of the drainfield. Nitrates can play a role in the methhemoglobinemia syndrome observed in infants.

Hines *et al*. (1977) discussed sand filters, ET units, and aerobic lagoons as alternatives to the septic tank and leach field. They indicated that sand filter systems function well in Illinois, and that the systems are easy to design, construct, and maintain. They also indicated that aerobic lagoons have many restrictions due to lot size, city and county codes, and management and maintenance requirements. Flack (1976) also discusses a number of alternative wastewater systems presently being used or evaluated.

Evapotranspiration systems are presently being evaluated mainly for areas where leach fields are not suitable. A survey of state

health agencies indicated that about 5000 ET type systems are presently in use throughout the United States (Hines et al. 1977). The ET units were generally of two types. One type, sometimes referred to as a mount system, does not have an impermeable liner and thus allows for seepage as well as evapotranspiration. The other allows no seepage and is thus non-discharging. The one we studied is of the non-discharging type.

Experimental work on ET units was first carried out by Bernhardt (1964, 1973). He used a system which allowed both seepage and evapotranspiration. A septic tank preceded the ET unit, and he used a bed depth of 45.7 cm (18 inches) composed of sand and a few cm of topsoil was used. Smith (1965) used highly impermeable soils as a membrane system to partially eliminate seepage. Several others have investigated the mound-type system since these early studies. Witz et al. (1970) and Lubinus and Nelson (1975) discussed an above-ground evapotranspiration system (called the Nodak System) which was suggested for use on farms and rural areas with clay subsoil or a high water table. The system is preceded by a septic tank and is unlined. Converse et al. (1977), Wooding (1975), and Machmeier (1977) have made adaptations and modifications to the Nodak system for use with other soil and climatic conditions.

Bernhardt's (1973) pioneering work on the non-discharging type ET units indicated they can be used successfully for wastewater disposal. Tanner and Bauma (1975) evaluated the potential for use of a non-discharging type ET unit in Wisconsin. Utilizing an energy balance technique for determining evapotranspiration, they indicated that the non-discharging type unit was not feasible because rainfall exceeds potential evaporation. Maurer (1976) also indicated problems with non-discharging ET units in Pennsylvania. Hines et al. (1977) stated that non-discharging units are feasible only in semi-arid regions of the southwestern United States on a year-round basis, and to a limited extent (summertime use) in other regions. Bennett and Linstedt (1976) conducted a study to establish parameters and design criteria for non-discharging ET systems in Colorado. They found that, for year-around application, the evapotranspiration rate must substantially exceed precipitation for each individual month. Use of grasses and shrubs was found to increase moisture transfer during the warmer months but was ineffective in winter and early spring.

Studies on evapotranspiration units are presently being carried on at the University of Wisconsin, Auburn University, Pennsylvania State University, and the University of Wyoming as well as by state and federal agencies. In the high moisture regions of the United States (e.g. Alabama), precipitation-shedding structures are being constructed which still allow sunlight incident upon the vegetation. In the colder semi-arid climates (e.g. Wyoming), covered solar-type units are being tested for fall, winter, and spring operation and for the relative effects of elevation.

THE EVAPOTRANSPIRATION UNIT

Location

An experimental evapotranspiration unit (ET unit) was constructed northwest of Laramie, Wyoming, and next to the Laramie City Lagoon System in an effort to develop a safe and environmentally acceptable non-polluting waste disposal method for rural and mountain second homes. Laramie is located in the southeastern part of Wyoming at an elevation of approximately 2195 m (7200 ft) on a high mountain plain which produces mainly short grasses and sagebrush. The mean annual rainfall is 28.2 cm (11.1 inches) and the mean annual temperature is 6°C (43°F), with a range from 34°C (93°F) to -37°C (-35°F). The mean annual lake evaporation is approximately 127 cm (50 inches) and the average daily evapotranspiration rate during the summer is 0.66 cm per day (0.26 inches/day). The Laramie area is also characterized by relatively low humidity (10-20 percent) and a mean wind speed of 8.1 kilometers per hour (5 mph). The location provided an area which had easy access to a source of wastewater and was in close proximity to laboratory facilities, yet had features similar to mountain areas. A meteorological station is also situated at the ET site, so that precipitation, evaporation, temperature, wind speed, and humidity could be measured.

Construction

Figure 1 shows a cross-sectional view of the ET unit. The unit measures 12.2 m (40 ft) x 9.1 m (30 ft) x 1.52 m (5 ft) deep ; the rubber liner is 22 mil nylon-reinforced, polyvinyl chloride rubber. A center opening of 3.05 m (10 ft) x 4.0 m (13 ft) was left for loading and to provide observation of the wastewater. The size of the ET unit was selected based on an initial estimate of a six person family yielding 190 liters (50 gallons) per person of wastewater each day for five days of the week, and the average ET rate for Laramie of 0.66 cm per day.

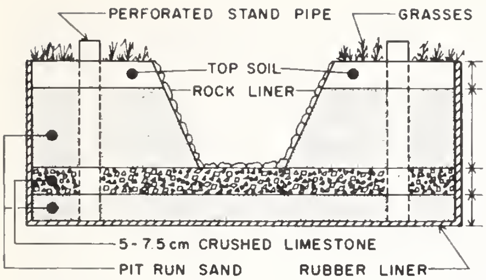


Figure 1. A Cross-Sectional View of the Evapotranspiration Unit.

Excavation and Backfill

The equipment to be used in excavating the site for the ET unit will depend on the type of soil at the site. The soil at the Laramie site was a clay loam topsoil with a clay subsoil to a depth of 100 cm (40 inches) and then a cobble-sand-silt material below this depth. The method found best for excavation was a backhoe which would keep the sides fairly vertical. However, in this type material a front-end loader is also feasible. The sides of the Laramie ET Unit were kept as nearly vertical as possible. The bottom was raked to remove sharp objects that could cut the liner. The impermeable liner was placed in the excavation so that at least 7 to 15 cm (3 to 6 inches) were above ground surface on all sides of the unit.

With the liner in place, 30.5 cm (1 ft) of sand was placed in the cavity (fig. 1) to ensure water movement and liner protection; 30.5 cm (1 ft) of 5 to 7.5 cm (2-3 inch) gravel was then placed on top of the sand. The gravel layer was used to help reduce the possibility of clogging and to disperse the liquid waste throughout the unit more rapidly. Another 76 cm (1.5 ft) of sand was then added and the unit was topped with 15 cm (6 inches) of topsoil. The center opening was lined with the 5 to 7.5 cm gravel. The filler material (sand and gravel) was placed with a front-end loader and smoothed by hand. It has been found that a more efficient method is to use a concrete batch mix truck to haul the sand and gravel for placement. Four 10 cm (4 inch) diameter perforated standpipes, which extend to the full depth of the unit, were placed close to each of the corners of the unit for water level and water quality measurements.

Sand and gravel materials were used as the filler for the unit to provide sufficiently large pore spaces to reduce the possibility of chemical, physical, and/or biological clogging (McGauhey and Winneberger 1975; DeVries 1972; Lance and Whisler 1972; Thomas et al. 1972; Jones 1965; and Rice 1974). Later units that have been developed use the existing soil for the top 91 cm (3 ft). This allows for reduced cost where the soil materials are suitable. Soils with high clay contents or other characteristics which would give them a high resistance to water movement are unsuitable for this purpose. Highly alkaline soils may also be unsuitable as they may inhibit plant growth. The center opening is not necessary in actual operation, and could be replaced by a small perforated tank fed from the supply line in the crushed gravel section of the unit and the opening filled with the same material as specified for the rest of the unit. The perforated tank would disperse the wastewater and trap non-decomposible material which could be removed periodically if a standpipe extended to the surface of the unit from the tank. There may be some advantage to either a center opening or a feed pipe extending to the surface over a totally subterranean distribution system. There is some indication that the pipes or center opening provide ventilation, allowing more rapid aerobic degradation of organic matter than might be expected in a totally anaerobic system.

It should be noted that this unit did not use a separate septic tank before discharging wastewater. This type of unit must be placed at an elevation low enough that it will not backup the wastewater into the house when full. If this is not possible, a pump system will have to be used to inject wastewater to the unit.

Grasses

A mixture of grasses which included tall fescue, orchard grass, reed canary grass, and alfalfa was planted in the topsoil of the unit immediately upon completion of construction in August, 1973. The selection of these grasses was based on representative types of grasses grown in the Laramie area, on varying root penetrations, and on salt tolerance (Agriculture Handbook 60, 1954). A second seeding was performed in the spring of 1974 since the stand of grass from the previous fall planting did not afford excellent coverage. By the fall of 1974 the unit was approximately 75 percent covered by grasses, mainly orchard grass, tall fescue, and reed canary grass. Alfalfa did not thrive in the wet conditions, while a number of native grasses from the area surrounding the ET unit have seeded themselves within the unit. By September, 1975, the unit was approximately 85 percent covered with grasses which were from two to six feet in

height.

It is important to plant a mixture of grasses on the unit so that those which can tolerate the conditions will flourish. As the dissolved solids in the unit increase, it will be interesting to see the effect on plant growth and types of grasses which will survive under these conditions. After three years of operation, the grasses are not being affected by the dissolved solids.

Besides the above grasses, Kentucky bluegrass is presently being evaluated on a unit in Laramie. In some areas, shrubs and trees have been planted inside lined units and found to function favorably (Bennett and Linstedt 1975).

Operation of the Unit

The ET unit was operated continuously from the middle of August, 1973, except during the winter of 1973-74, until September, 1975. Raw wastewater was added daily, except Saturday and Sunday, to the unit and the amount was varied over the project length. The water level in the unit was monitored before and after the raw wastewater was added. Water quality samples of the raw wastewater and the wastewater within the unit were obtained at least three times weekly during the summer months and intermittently during the winter and analyzed for BOD, suspended and volatile solids, and total coliforms. Random testing of pH, temperature, dissolved oxygen, magnesium, calcium and sodium was also done.

Loading

Untreated wastewater for the ET unit is taken directly from a trunk sewer line of the Laramie City System and transported by truck to the unit, where it is discharged into the center opening.

The amount of wastewater that can be added to an ET unit is mainly affected by evapotranspiration, except during the winter where sublimation is the main factor. The factors which are generally accepted as having the most influence on evapotranspiration are solar radiation, temperature, elevation, relative humidity, wind speed, soil moisture availability, plant density, and surface area. Since these factors are greatly affected by geographic location, the Laramie site has favorable conditions for solar radiation, wind speed, and relative humidity. The disadvantages of this site are temperature and elevation, but these would be a problem for any mountain environment.

As a result of the variability of evapotranspiration, the loading rate for the ET unit was varied over the period of the investigation from a maximum of 6,265 liters (1,655 gallons) to a minimum of zero for a given 7-day period.

Tables 1 and 2 give the weekly loading rates for summer and winter operation, respectively. The loading rates cited are for that weekly period; any precipitation during the same period is in addition to the amounts indicated. The actual evapotranspiration amounts shown in Table 1 were determined from a water budget analysis of the unit. The water budget analysis yields the actual evapotranspiration in centimeters by comparing the amount of raw wastewater added to the ET unit plus any precipitation (in centimeters over the area of the unit) to the change in liquid level in the ET unit for the week. The change in liquid level in centimeters multiplied by the porosity of the unit (24.08%) results in centimeters of liquid over the area of the unit. A positive value of liquid level difference means a drop in the actual water level. Average daily ET is obtained by dividing actual weekly ET by seven.

Table 2 shows wastewater added, precipitation, and water level changes as measured. Determination of the ET or sublimation rates for a portion of the winter period was not attempted because of the variability created in the water level measurements as a result of the unit freezing. Also, the loading was not on a regular basis and snow drifts occurred on the unit.

Operation

To determine the ability of an ET unit to perform under the conditions existing in Laramie, it was necessary first to determine the quantity of wastewater which could be applied to the unit without producing extremes of moisture levels in the root zone of the grasses on the unit surface. Prior to each application of wastewater, liquid elevation readings were taken from the four standpipes in the corners of the unit. As might be expected, the fluctuations in liquid elevations depended primarily on the wastewater loading being applied. During the initial startup of the unit in August, 1973, approximately 5675 liters (1,500 gallons) of wastewater were applied to the unit per week, part of which was sprayed on the surface to encourage the germination and initial growth of the grasses. Application of the wastewater was discontinued in November

Table 1. Actual Weekly and Average Daily Evapotranspiration for Summers of 1973-1975.

a	b	c	d	e	f	g	h	i	j
Date	Sewage Added (liters)	Precipitation (cm)	Water Elevation Beginning (m)	Water Elevation End (m)	Diff. in Water Elevation (m)(d-e)	Sewage (cm)	Water Diff. (+,-) (cm)	Actual Weekly ET (cm) (g + h + c)	Average Daily ET (cm) (i/7)
1973									
8/27-9/2	6435.20	0.15	2192.91	2192.76	+.15	5.7724	+3.6624	9.5848	1.3693
9/3-9/9	3406.87	0.53	2192.76	2192.80	-.04	3.0559	-0.8057	2.7802	0.3972
9/10-9/16	4542.49	3.07	2192.80	2192.83	-.03	4.0747	-0.7325	6.4122	0.9160
9/17-9/23	5678.12	0.00	2192.83	2192.81	+.02	5.0932	+0.2931	5.3863	0.7695
9/24-9/30	3406.87	1.42	2192.81	2192.84	-.03	3.0559	-0.7325	3.7434	0.5348
10/1-10/7	3406.87	0.00	2192.84	2192.81	+.03	3.0559	+0.7325	3.7884	0.5412
10/8-10/14	2271.25	0.10	2192.81	2192.80	+.01	2.0373	+0.3663	2.5036	0.3577
10/15-10/21	5678.12	0.00	2192.80	2192.83	-.03	5.0932	-0.8057	4.2875	0.6125
10/22-10/28	4542.49	0.00	2192.83	2192.82	+.01	4.0747	+0.2931	4.3678	0.6240
1974									
5/1-5/7	5867.39	0.05	2192.75	2192.78	-.03	5.2629	-0.5860	4.7269	0.6753
5/8-5/22	Insufficient Data								
5/23-5/29	6245.93	0.08	2192.78	2192.79	-.01	5.6025	-0.2931	5.3894	0.7699
5/30-6/5	6264.86	0.00	2192.79	2192.82	-.03	5.6025	-0.6594	4.9431	0.7062
6/6-6/16	Overflow								
6/17-6/23	4163.95	0.10	2192.80	2192.77	+.03	3.7351	+0.6594	4.4945	0.6421
6/24-6/30	4353.22	0.00	2192.77	2192.76	+.01	3.9047	+0.2197	4.1244	0.5892
7/1-7/7	3785.41	0.13	2192.76	2192.75	+.01	3.3955	+0.2197	3.7452	0.5350
7/8-7/14	4542.49	0.28	2192.75	2192.75	.00	4.0747	-0.0732	4.2815	0.6116
7/15-7/21	3406.87	2.06	2192.75	2192.76	-.01	3.0559	-0.3663	4.7496	0.6785
7/22-7/28	6056.66	0.41	2192.76	2192.83	-.07	5.4326	-1.5382	4.3044	0.6149
1975									
6/2-6/8	1892.71	0.79	2192.77	2192.75	+.02	1.6977	+0.5860	3.0737	0.4391
6/9-6/15	3785.41	0.33	2192.75	2192.76	-.01	3.3955	-0.2931	3.4324	0.4903
6/16-6/22	3785.41	1.04	2192.76	2192.83	-.07	3.3955	-1.6116	2.8239	0.4034
6/23-6/29	3785.41	0.00	2192.83	2192.76	+.07	3.3955	+1.6116	5.0071	0.7153
6/30-7/6	3785.41	1.40	2192.76	2192.74	+.02	3.3955	+0.5860	5.3815	0.7688
7/7-7/13	5678.12	3.05	2192.74	2192.87	-.13	5.0932	-3.1493	4.9939	0.7134
7/14-7/20	5678.12	0.69	2192.87	2192.87	.00	5.0932	0.0000	5.7832	0.8262
7/21-7/27	4731.76	0.94	2192.87	2192.84	+.03	4.2443	+0.6594	5.8437	0.8348
7/28-8/3	4731.76	0.20	2192.84	2192.79	+.05	4.2443	+1.1720	5.6163	0.8023
8/4-8/10	3785.41	0.13	2192.79	2192.73	+.06	3.3955	+1.5380	5.0635	0.7234
8/11-8/17	3974.68	1.09	2192.73	2192.76	-.03	3.5651	-0.6591	3.9960	0.5709

when inclement weather made the unit inaccessible, and the unit was left dormant over the winter period. Operation was begun again in late April, 1974, at a rate of approximately 5700 liters/week (1510 gallons/week) and a relatively steady increase in liquid elevation occurred in the unit until it overflowed in mid-June (Table 1). When the liquid loading was decreased to approximately 4165 liters/week (1100 gallons/week) a steady decline in the liquid elevation resulted. However, when the liquid loading was increased to 6200 liters/week (1600 gallons/week) the liquid level rose rapidly and produced an overflow at one point at the side of the unit. Loading at a rate of 1950 liters/week (550 gallons/week) was found to reduce the liquid elevation rapidly to a point that could result in plant stresses. It would appear that the feasible loading rate for a unit of the size studied lies somewhere in the range of 4000 liters/week (1035 gallons/week) from Table 1 for summer use. A more indepth sizing will be presented later in this paper.

During the week of July 26, 1974, it was noticed that the unit was overflowing. This was due to the high loading rate of 6450 liters/week (1665 gallons/week) and a small area where the liner was about 10 cm (4 inches) below the top of the unit. As a result of this overflow, the liquid level was lowered in the unit (Table 2) and the liner raised to the surface of the unit in the area in question.

Loading was again undertaken on August 30, 1974. The liquid elevation in the unit climbed steadily after August 30 even though the loading rates did not seem excessive. However, on September 3, 1974, the temperature in Laramie dropped to $-10^{o}C$ ($13^{o}F$) which caused the grasses to become dormant. Cold temperatures remained throughout the month of September. The reduction in evapotranspiration was quite dramatic, as indicated by the raise in liquid level after this period. In October, 1974, precipitation was high, approximately 3.3 cm (1.3 inches). The precipitation and the loading on the unit resulted in its filling. The unit was again lowered in liquid elevation at the end of October.

In November, 1974, the ET unit was loaded at an average rate of 585 liters/week (150 gallons/week) and the liquid elevation remained fairly constant. Ice began to form in the

Table 2. Actual Weekly and Average Daily Evapotranspiration for the Winter of 1974-1975.

a Date	b Sewage Added (liters)	c Precipi-tation (cm)	d Water Elevation Beginning (m)	e Water Elevation End (m)	f Diff. in Water Elevation (m)(d-e)	g Sewage (cm)	h Water Diff. (+,-) (cm)	i Actual Weekly ET (cm) (g+h+c)	j Average Daily ET (cm) (i/7)
1974									
7/29-8/4	7570.82	1.57	2192.81	2192.84	-.03	6.7911	-0.7224	7.6387	1.0912
8/5-8/11	0	3.02	2192.84	2192.83	+.01	0	+0.2408	3.2608	0.4658
8/12-8/18	0	0.00	2192.83	2192.77	+.06	0	+1.4448	1.4448	0.2064
8/19-8/25	3406.87	0.00	2192.77	2192.66	+.11	3.0560	+2.6488	5.7048	0.8150
8/26-9/1	1362.75	0.18	2192.66	2192.69	-.03	1.2224	-0.7224	0.6800	0.0971
9/2-9/8	4542.49	0.00	2192.69	2192.69	0.00	4.0746	0.0000	4.0746	0.5821
9/9-9/15	1135.62	1.12	2192.69	2192.76	-.07	1.0187	-1.6856	0.4531	0.0647
9/16-9/22	4542.49	0.00	2192.76	2192.84	-.08	4.0746	-1.9264	2.1482	0.3069
9/23-9/29	4921.04	0.00	2192.84	2192.89	-.05	4.4142	-1.2040	3.2102	0.4586
9/30-10/6	3406.87	0.36	2192.89	2192.91	-.02	3.0560	-0.4816	2.9344	0.4192
10/7-10/13	757.08	0.69	2192.91	2192.91	0.00	0.6791	0.0000	1.3691	0.1956
10/14-10/20	0	0.66	2192.91	2192.91	0.00	0	0.0000	0.6600	0.0943
10/21-10/27	0	1.83	2192.91	2192.91	*	*	*	*	*
10/28-11/3	757.08	1.04	2192.91	2192.78	+.13	0.6791	+3.1304	4.8495	0.6928
11/4-11/10	757.08	0.00	2192.78	2192.77	+.01	0.6791	+0.2408	0.9199	0.1314
11-11-11/17	378.54	0.81	2192.77	2192.77	0.00	0.3396	0.0000	1.1496	0.1642
11/18-11/24	378.54	0.00	2192.77	2192.77	0.00	0.3396	0.0000	0.3396	0.0485
11/25-12/1	378.54	0.64	2192.77	2192.76	+.01	0.3396	+0.2408	1.2204	0.1743
12/2-12/8	378.54	0.38	2192.76	2192.73	+.03	0.3396	+0.7224	1.4420	0.2060
12/9-12/15	0	0.00	2192.73	2192.71	+.02	0	+0.4816	0.4816	0.0688
12/16-12/22	567.81	0.00	2192.71	2192.72	-.01	0.5093	-0.2408	0.2685	0.0384
12/23-12/29	0	0.00	2192.72	2192.76	-.04	0	**	**	**
1975									
12/30-1/5	0	0.00	2192.76	2192.76	0.00	0	0.0000	0.0000	0.0000
1/6-1/12	0	0.00	2192.76	2192.75	+.01	0	+0.2408	0.2408	0.0344
1/13-1/19	378.54	0.46	2192.75	2192.75	0.00	0.3396	0.0000	0.7996	0.1142
1/20-1/26	567.81	0.25	2192.75	2192.75	0.00	0.5093	0.0000	0.7593	0.1085
1/27-2/2	0	0.28	2192.75	2192.76	-.01	0	-0.2408	0.0392	0.0056
2/3-2/9	0	0.15	2192.76	2192.96	-.20	0	**	**	**
2/10/2/16	0	0.33	2192.96	2192.94	+.02	0	**	**	**
2/17-2/23	0	0.00	2192.94	2193.05	-.11	0	**	**	**
2/24-3/2	567.81	0.00	2193.05	2193.15	-.10	0.5093	**	**	**
3/3-3/9	0	0.28	2193.15	2193.11	+.04	0	**	**	**
3/10-3/16	0	0.05	2193.11	2193.10	+.01	0	**	**	**
3/17-3/23	0	0.58	2193.10	2193.10	0.00	0	**	**	**
3/24-3/30	0	0.89	2193.10	2193.08	+.02	0	**	**	**
3/31-4/6	0	0.28	2193.08	2193.11	-.03	0	**	**	**
4/7-4/13	0	0.15	2193.11	2193.06	+.05	0	+1.2040	1.3540	0.1934
4/14-4/20	0	0.25	2193.06	2193.02	+.04	0	+0.9632	1.2132	0.1733
4/21-4/27	0	0.56	2193.02	2192.85	+.17	0	+4.0936	4.6536	0.6648
4/28-5/4	0	0.00	2192.85	2192.89	-.04	0	**	**	**
5/5-5/11	0	0.00	2192.89	2192.82	+.07	0	+1.6856	1.6856	0.2408
5/12-5/18	0	0.00	2192.82	2192.74	+.08	0	+1.9264	1.9264	0.2752
5/19-5/25	0	0.05	2192.74	2192.86	-.12	0	**	**	**
5/26-6/1	378.54	0.99	2192.86	2192.77	+.09	0.3396	+2.1672	3.4968	0.4995

Note: *Indicates that the unit was dewatered due to overflow during that period of time.

**Indicates negative ET which could have been a result of snowmelt runoff from drifts on unit or a measurement error.

center opening at night starting early in November. On December 2, 1974, the center opening stayed frozen the entire day and by December 6 the entire unit was frozen. Efforts were made to keep the center opening clear of ice but without success. A shelter was constructed over the center opening in hopes of retaining some heat. However, the temperature inside the shelter averaged only 2 to 3^{o}C warmer than the outside air. A small heating element was also tried without success. Due to the small amount of influent being added on a weekly basis, the amount of heat input and heat generated by the system were far below that necessary to keep the unit from freezing.

Once the ET unit had completely frozen throughout, the amounts of evaporation, transpiration, and sublimation were so small that only 2130 liters (550 gallons) were added to the unit other than precipitation and drifting snow until mid-May, 1975. The ice layer formed during this period thickened to a maximum of 73 cm (2.4 ft) on February 28, 1975, causing the liquid elevation to continue to rise. The ice actually put the water in the unit under pressure; when trying to obtain water quality samples by rodding through the ice, the water would gush out of the hole. As a result of the ice layer, it was difficult to actually get a true measure of the liquid elevation in the unit. From Table 2 it can be seen that the elevation in the unit remained high until thawing started late in April, 1975. As the

unit thawed, the liquid elevation declined.

It was interesting to note how the unit acted as an insulator to freezing in the fall and how it prevented the unit from thawing in the spring. In the fall, the Laramie Lagoon System was frozen two weeks ahead of the unit, but thawed two weeks earlier in the spring.

The winter operation of the ET unit indicates that it cannot handle any large quantity of wastewater. Research efforts to provide a heat shelter for the unit to make it effective during the cold months of the year are presently being investigated by the authors.

WATER QUALITY

Samples of the applied wastewater and the liquid reaching the standpipes were analyzed over the entire study to determine the ability of the unit to reduce the concentration of important wastewater constituents. The unit has no effluent as such, but it is important that the portions of the wastewater which can be broken down by the action of bacteria within the unit be determined. Without some means of removing the degradable portions of the wastewater, these materials would accumulate and eventually cause the unit to become clogged and useless. The pores in the sand and gravel must be kept open to allow the liquid to move to the surface of the unit and be carried away by the evapotranspiration process.

As mentioned earlier, water quality samples of the raw wastewater (influent) and the wastewater within the unit (effluent) were obtained three times a week during the summer months, and analyzed for BOD, suspended and volatile solids, and total coliforms. Random testing of pH, temperature, dissolved oxygen, magnesium, calcium and sodium was also done. Diurnal measurements of BOD, solids and coliforms were also made.

Biochemical Oxygen Demand

Biochemical oxygen demand (BOD) is a measure of the oxygen required by bacteria to break down organic matter present in wastewater. Thus, it may be regarded as an indirect measure of the organic matter present. Using recognized standard procedures, (A.P.H.A., 1972) the influent and standpipe liquids were analyzed for BOD. Removal varied considerably with time but did not appear to be related to the quantity of wastewater organic matter applied (fig. 2). This is an important point, since many treatment systems are sensitive to hydraulic and organic overloading and will produce poor quality effluents when subjected to shock loads. Package biological treatment plants in use at recreational sites in the Laramie area have shown considerable sensitivity to hydraulic and organic shock loads (Lindimore, 1975). Recreational sites generally produce wastewater erratically with considerable variation in volume generated and in concentration of polluting substances. Insensitivity to shock loading is a definite advantage for recreational treatment systems.

Solids

Various types of solid materials are present in wastewater, and may generally be divided into suspended and dissolved portions. Part of each category may be considered to be volatile, that is, made up of combustible or organic substances.

Dissolved inorganic substances, principally salts, may combine with soil particles in such a way that the soil becomes less permeable to water (McGauhey and Winneberger 1965; DeVries 1972; Lance and Whisler 1972 and Thomas, et al., 1972). In an ET unit, the salts present in the wastewater are left behind when the water leaves the unit by evapotranspiration. For the most part these salts will not be broken down by biological processes. As a result, salts tend to build up and may reduce the effective lifespan of the unit. Dissolved solids reaching the standpipes in 1973 were consistently above the influent levels (fig. 3). During 1974, the salt being applied frequently was less than the concentration found at the standpipes, particularly during the periods when the hydraulic loading was reduced. This tended to indicate a rather constant migration of salt to all parts of the unit. An overall increase in salts at the standpipes of the unit has been observed, but no effects of a salt buildup, either on the ability of the liquid to move through the unit or on the salt tolerant grasses growing on the unit surface have been noted.

Suspended solids are important because the particulates have a tendency to clog soil pores. With time, pores could become so thoroughly blinded as to render the unit useless unless the solids could be broken down. The volatile suspended solids represent the biodegradable portion of the suspended material. Total suspended solids (fig. 4) were removed fairly effectively by passage through the unit. Although effluent values occasionally rose above influent levels, no severe clogging problems were apparent. Volatile solids (fig. 5) were reduced from influent values, apparently due to biological activity in the soil within the ET unit. It would appear that

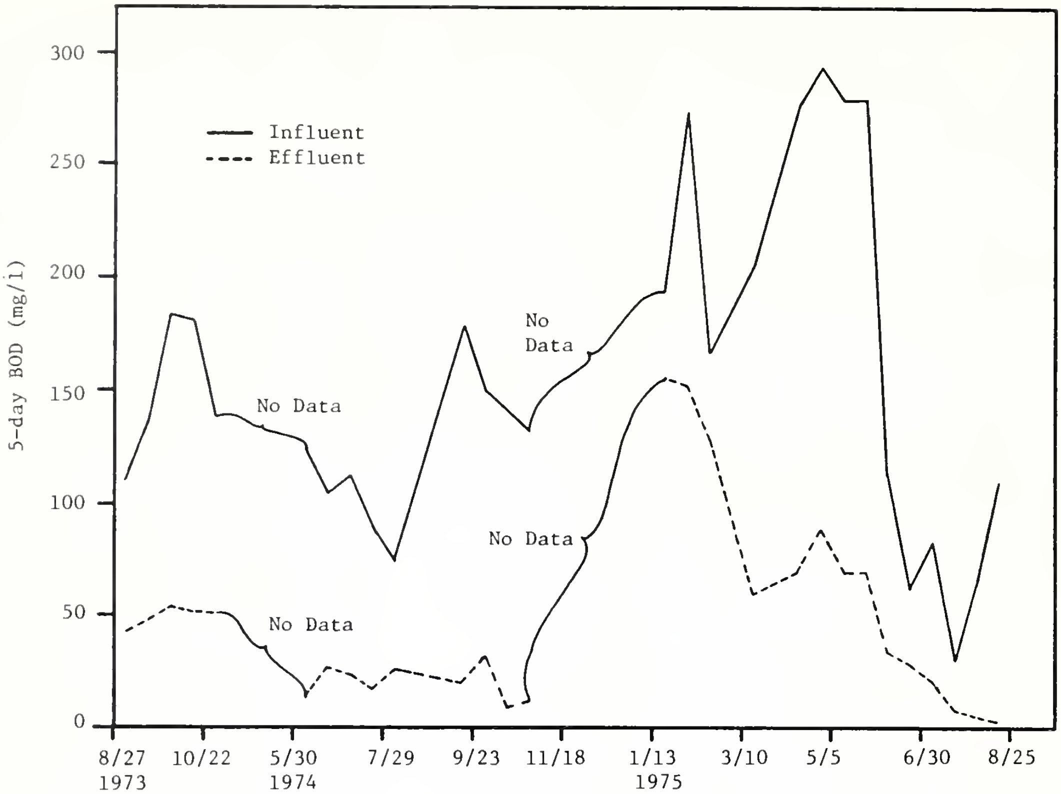


Figure 2. Biochemical Oxygen Demand (Biweekly average from August 1973 to August 1975).

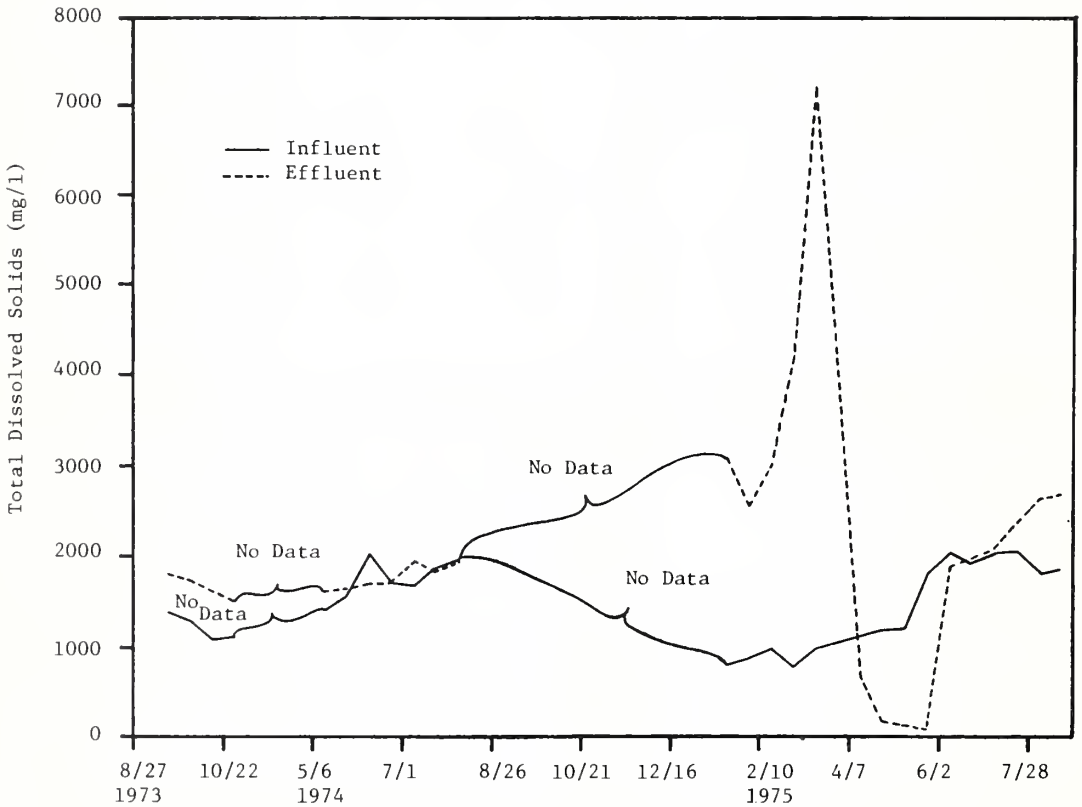


Figure 3. Total Dissolved Solids (Biweekly average from August 1973 to August 1975).

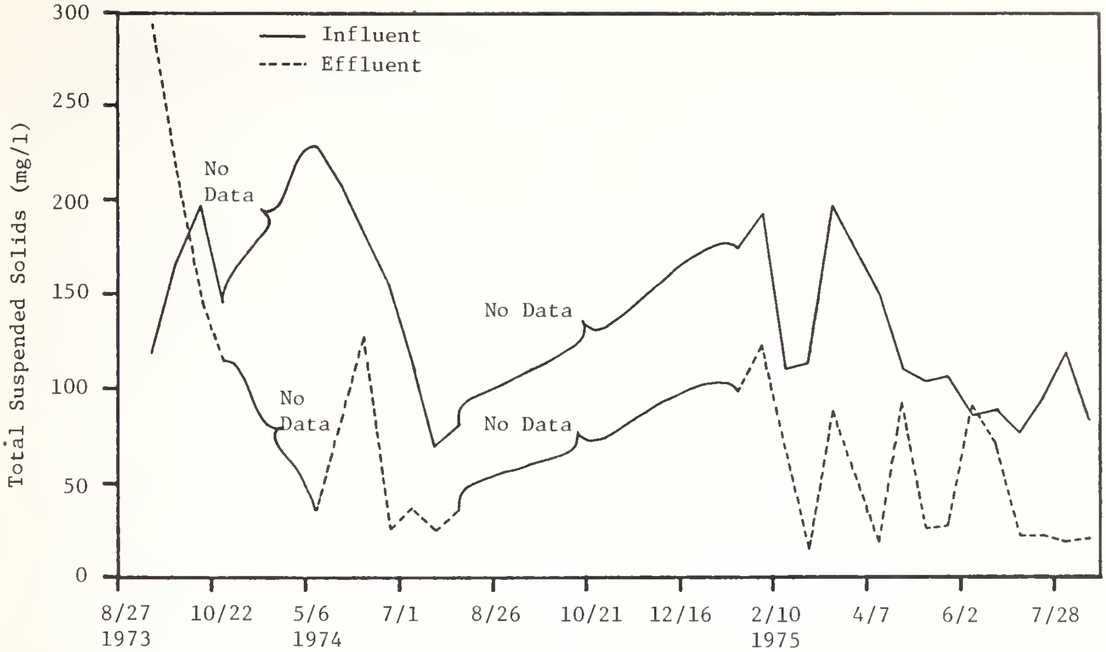


Figure 4. Total Suspended Solids (Biweekly average from August 1973 to August 1975).

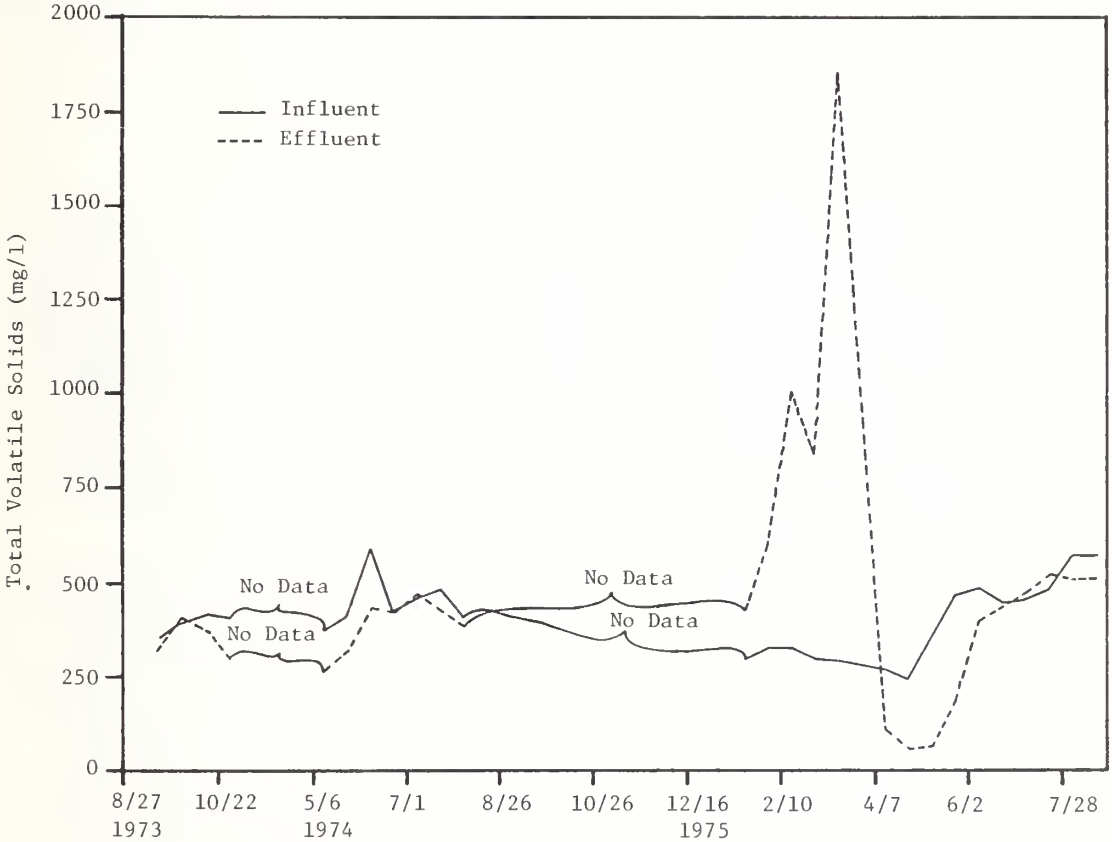


Figure 5. Total Volatile Solids (Biweekly average from August 1973 to August 1975).

the suspended solids would be reduced in part, at least, as biological action reduces the solids to gases and water. It is interesting to note that the volatile solids present in the unit at the beginning of 1974 were significantly less than levels observed at the end of operation in 1973, indicating that the removal of the organics continued during the winter months. Thus, the unit has the capacity to renew itself when given rest periods. The same type of occurrence also resulted during the winter period of 1974-75. The peak that resulted in February and March, 1975 is believed to be due to the amount of free water in the unit. As the ice thickness increased in the unit, putting the water under pressure, the water collected for the sample gushed, bringing more solid material with it than would normally result. The decrease in solids after this period is a result of dilution as the ice thawed. Some of the suspended solids probably combine during the freezing process, and are then settled out during the thawing process.

Since mountain second homes are not likely to be in use continuously over the entire year, rest periods would be an advantage of an ET system as long as the moisture available to the vegetative cover is sufficient to maintain growth.

The major problem associated with the solids would appear to be salt buildup rather than accumulation of suspended solids. The sodium adsorption ratio (SAR) is used in irrigation water studies to determine the hazard of salt toxicity to plants and the possibility of the salts causing changes in soil structure which would reduce the ability of the soil to transmit water through soil pores. Generally clay soils are more susceptible to damage than soils of low clay content. The ET unit construction would thus best meet long-term needs if a sandy subsoil is used. The observed SAR for the Laramie ET unit was 2.75 meq/l at a specific conductance of 2200 micromhos per cm. SAR values of this magnitude indicate that the water has a high salinity hazard to plants but a low sodium hazard (Agriculture Handbook, 1954). Plants vary widely in their tolerance to salt. By judicious selection of salt-resistant varieties, the ability of the unit to withstand the applied salt may be increased. All grasses used in the Laramie unit have an ability to withstand salts far greater than the levels currently observed. The potential for damage to the plants does exist, however, and might require the backflushing of the unit with low-salinity water at some future date. In addition, one must consider the possible sensitivity of the bacterial population to salt buildup, although this is not likely to be a critical factor since many bacteria present will be derived from the human intestinal tract where a high salt content prevails.

Coliforms

Coliforms are a group of bacteria present in the intestines of warm-blooded animals. Their presence in water is regarded as an indication that fecal contamination may have occurred and the water could possibly harbor disease-producing agents. While removal of coliform organisms (fig. 6) varied over a wide range in the unit, removal rates were consistently above 90 percent and reached a maximum removal of 99.9 percent. The quality of the liquid reaching the standpipes would not be considered acceptable for recreational or other purposes since the levels of coliforms remaining are still excessive. This is of no real importance in an ET unit, since no effluent would escape the unit except under the unlikely failure of the liner. In an underground disposal system such as a septic tank system, however, the potential for contamination of ground water would exist. If the percolating wastewater reached a well supply, frequently used in recreational homes, a public health hazard could result.

Diurnal Variations

The response of a treatment system to transient loads often is used as an indication of system stability. If the system is unperturbed by a sudden change in load then it is judged stable. Treatment systems that respond poorly to rapid changes in loading conditions suffer treatment quality while the system recovers. In an enclosed system, such as an ET unit, the recovery of the unit is important since its success depends in part on the ability of the unit to rid itself of materials which could lead to clogging of pores and build up of dissolved and suspended matter.

The transient loads applied to a system are often referred to as "shock loads," since a shock to a system often results from their application. Shock loads are of two main types: hydraulic shock loads and "organic" shock loads. Hydraulic shock loads are the result of sudden increases or decreases in flow and typically affect the system's dependence on removal of inorganic contaminants such as sediment. "Organic" shock loads refer to sudden changes in the nature of the waste itself. Organic shock loads can be of two different types: a change in overall waste strength but no shift in composition (quantitative shock loads) or a change in composition by the addition (or

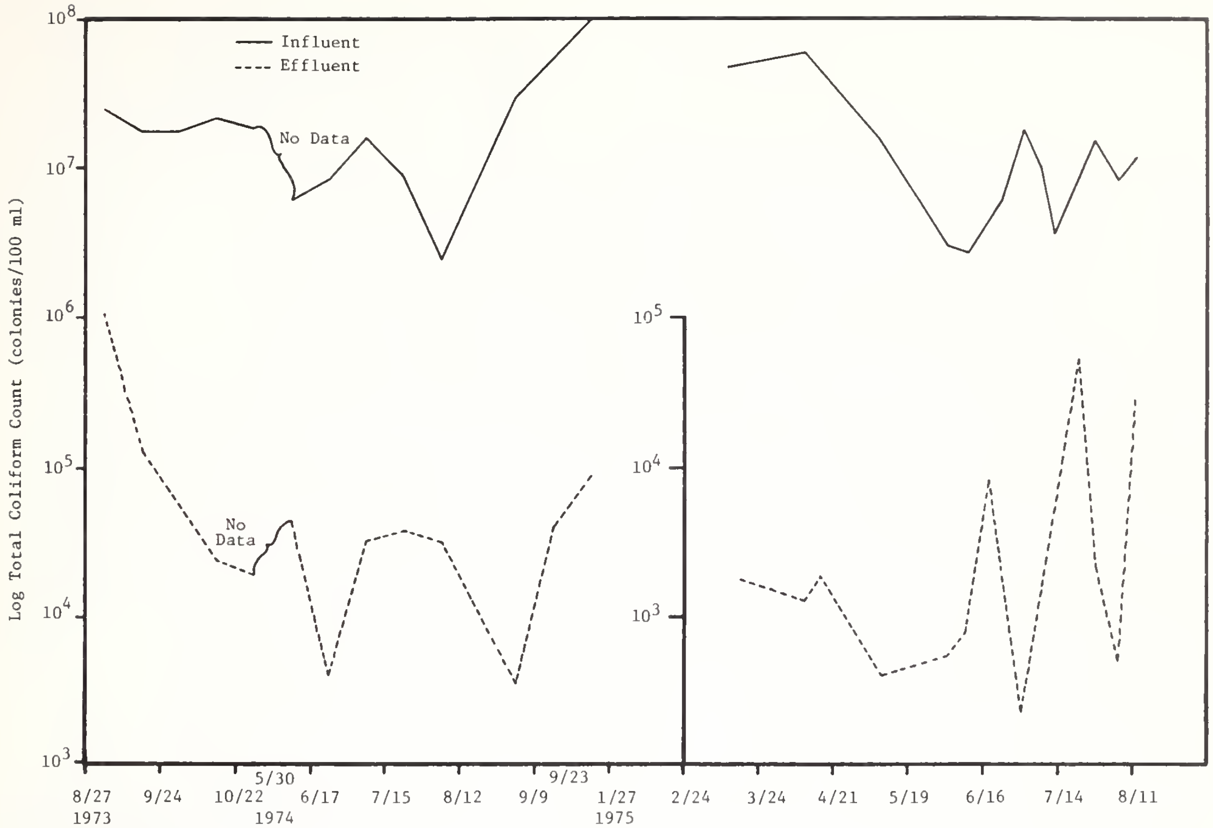


Figure 6. Total Coliform Count (Biweekly average from August 1973 to August 1975).

deletion) of a significant quantity of a new waste component (qualitative shock loads). In ET units, quantitative shock loads prevail but both types may occur. Generally shock loads tend to create instabilities in processes dependent on chemical or biological means to accomplish treatment. ET units accomplish their goals in part by these mechanisms and thus could be upset by sudden shifts in waste composition.

To examine the possible ramifications of shock loads on the function of an ET unit, the ET unit studied was hydraulically and organically dosed with wastewater and the impact of the dosing followed over a period of several days to determine if sudden loading of waste into the unit disrupts treatment efficiency. In addition, tap water was hydraulically applied to the unit in a second experiment to determine if a sudden decrease in waste strength had an adverse influence on the system's stability.

Figure 7 shows the behavior of the unit following dosing for volatile and non-volatile dissolved solids. The unit was dosed with raw sewage at the beginning of the experiment and at 26 hours. At 51.5 hours into the experiment the unit was dosed with a volume of tap water equivalent to an individual wastewater dose. The dissolved solids at the center opening responded to each dosing. The solids are initially high after first dosing with wastewater and decline until the second dosing when they rise again. Following dosing with water the dissolved solids at the point of application in the center opening drop precipitously. The volatile solids very nearly parallel the total dissolved solids in the center opening. The decline in dissolved solids is most likely due to destruction of the volatile solids by microbial action.

The dissolved solids at the standpipes (fig. 7) at the start of the experiment are higher by a significant margin over those at the center opening. As the dissolved materials move out into the unit with the fluid flow, water is lost by evaporation and transpiration, and the dissolved materials become concentrated. Thus, the distribution of dissolved solids will not be uniform during periods of waste application, but will tend to increase in concentration as the perimeter of the unit is approached. When dosing is stopped for any

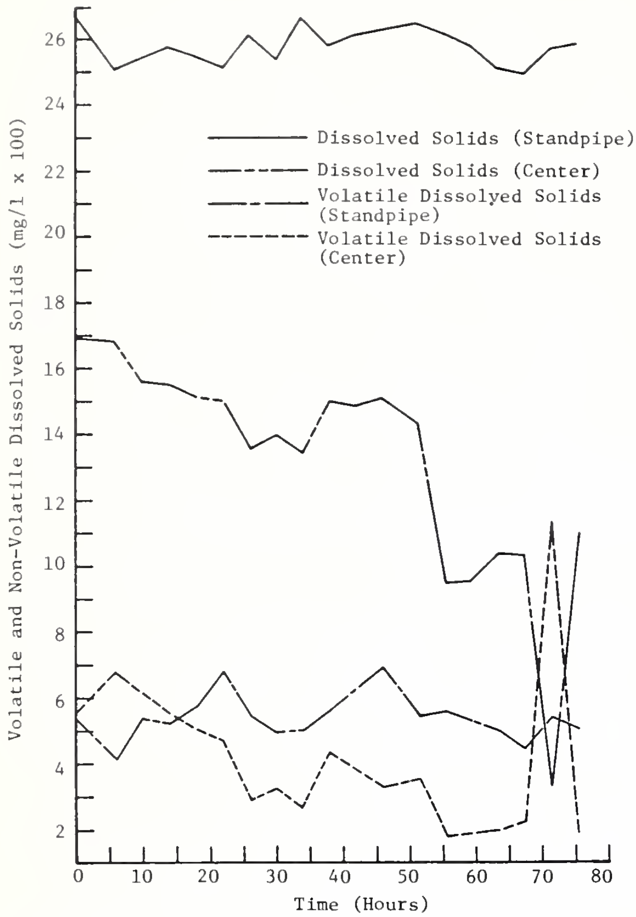


Figure 7. Diurnal Variations in Volatile and Non-Volatile Dissolved Solids.

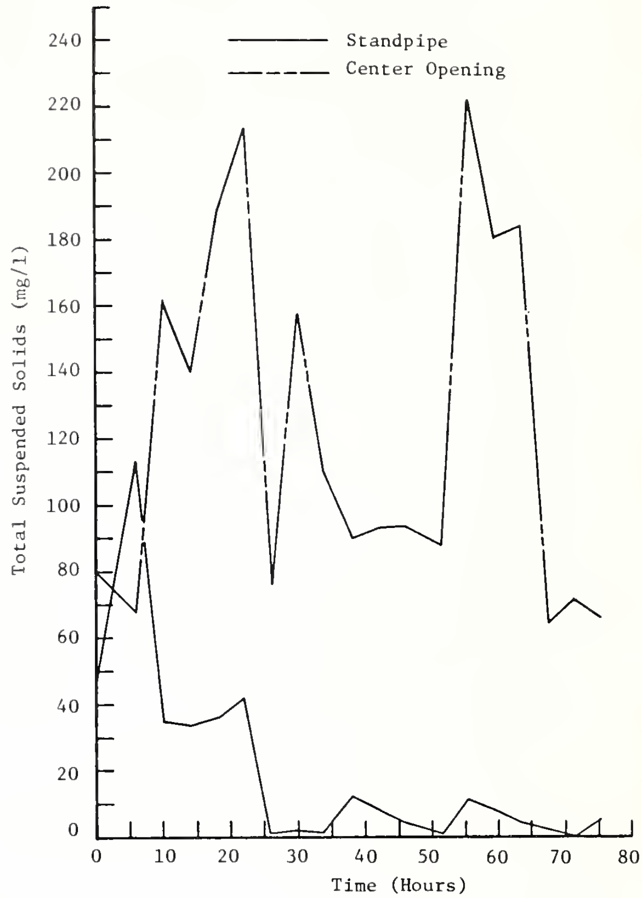


Figure 8. Diurnal Variations in Total Suspended Solids.

extended period such as during a winter rest period, the dissolved solids redistribute themselves by diffusion throughout the unit.

Volatile dissolved solids are much closer in concentrations at the center opening and standpipes. The concentration effect of evaporation is counteracted in this case by biodegradation of the dissolved organic matter in the waste. In both the case of total dissolved and volatile dissolved solids, the values obtained at the standpipes are remarkably stable when compared to those obtained at the center opening. This indicates that the unit is not seriously influenced by either hydraulic or organic shock loads due to dissolved materials.

The behavior of total and volatile suspended solids during the experiment are shown in figures 8 and 9. The suspended solids at the center opening varied from 64 to 222 mg/l and increased following each waste application. In fact, they increased even after water was applied indicating that the act of applying the waste stirs up previously settled solids. This would allow solids to have several opportunities to move out into the system and be stored or decay. It is also likely that the waste application breaks down the physical size of some solids making their transport out into the unit's pore spaces more readily accomplished.

The total suspended solids at the standpipes varied from zero to 113 mg/l. Only one value exceeded 50 mg/l and most values were below 10 mg/l. The volatile suspended solids at the standpipe were also low. There is an indication that the first loading may have caused a temporary instability in the system. In water treatment filters it has been observed that transient hydraulic shock loads will cause disturbance of deposited suspended solids and

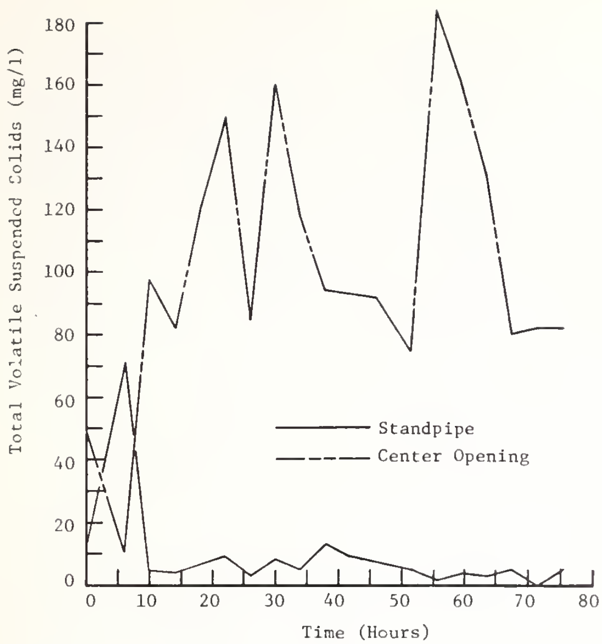


Figure 9. Diurnal Variations in Total Volatile Suspended Solids.

that redeposition further along the direction of flow occurs (Cleasby, 1963). This may be the explanation of the initially high suspended solids values at the standpipes. In general, however, the suspended solids values at the standpipes are quite stable.

The affect of transient loads on pH values is shown in figure 10. Both influent and standpipe values are rather invariant. The range at the standpipes is only 0.4 pH units while that at the center opening is 1.3 pH units. It is interesting to note that the standpipe pH is consistently below that at the center opening. This is another indication of biological action within the unit. The degradation of organic matter is accompanied by the production of gases particularly carbon dioxide. When the carbon dioxide is dissolved in the surrounding liquid it depresses the pH. Two different coliform strength experiments were performed on the unit. The values for the coliforms in the first experiment are shown in figure 11. The unit was dosed in this experiment at the beginning of the experiment and at 18 hours. The coliforms within the center opening did not show a typical die-off pattern until a considerable period of time had elapsed following the second dosing. After 48 hours the coliforms declined rapidly. With the exception of one

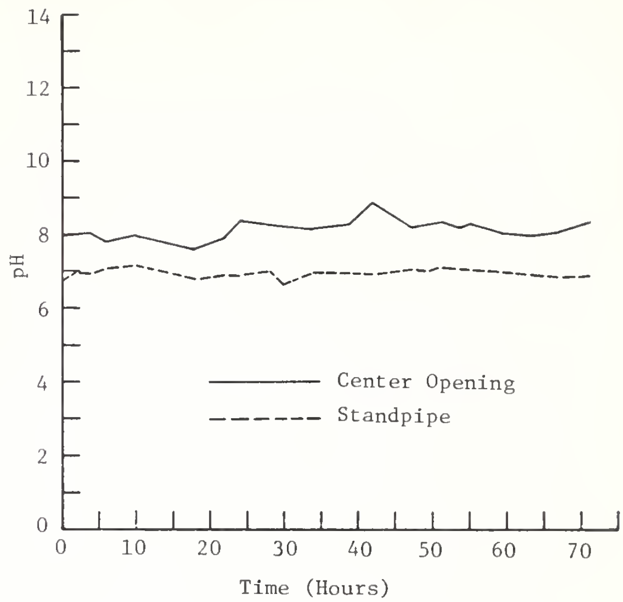


Figure 10. Diurnal Variations in pH.

probably spuriously low value at 51.5 hours, the decay approximated a straight line. Since the plot is semi-logarithmic, this would indicate a typical first order decay as predicted by Chick's Law (Metcalf and Eddy 1972). The removal of coliforms by whatever mechanism is at least three orders of magnitude (i.e. more than 99.9 percent) in all cases. No coliform value at the standpipe is greater than 50 coliforms per 100 ml. This would indicate that the system treats the applied waste to a degree that would tend to make it reasonably safe from a health standpoint should an accidental discharge from the unit occur. The coliform values at the standpipes vary from 7 to 50 per 100 ml, a relatively narrow range. Raw waste coliform densities, on the other hand, ranged from 800 to 84,000 coliforms per 100 ml. Thus, while the influent values fluctuated widely, the levels of coliforms experienced at the standpipes remained uniform.

A second experiment (fig. 12), corresponding to the data previously discussed, was performed using a wastewater with a higher initial coliform concentration (28,000,000 per 100 ml) than the first experiment. From an initial value of 30,000 per 100 ml the coliform level in the center opening rose to 3,500,000 per 100 ml following dosing. A second dose at 24 hours more than doubled the coliform concentration in the center opening while a water dose at 51.5 hours resulted in a precipitous initial decline in coliform levels observed. An increase in coliforms at the dosing point then occurred which was similar

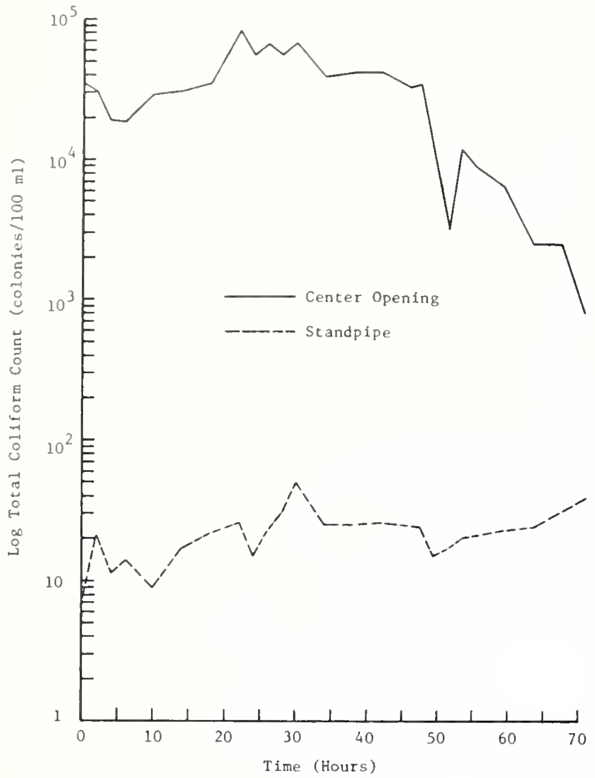


Figure 11. Diurnal Variations in Coliforms Under First Dosage.

to that observed for suspended solids (fig. 8). It is likely that the phenomenon is due to resuspension of material settled out in the center opening and dispersion of aggregated bacteria by shear forces and perhaps by chemical factors related to the change in waste strength.

The coliform levels at the standpipes indicated a gradual rise throughout the course of the experiment. In this experiment there appears to be a parallel between events occurring in the center opening and at the standpipes. Unit stability was thus affected by the dosing regime when a moderate (versus low) strength waste was applied. Coliform levels reached 4600 per 100 ml 10 hours after the second dose. High waste strengths are likely to be encountered in situations such as mountain second homes where only small quantities of liquid would be used for carriage water. The dilution of human wastes in such a situation would be small (Ward, 1977). Thus with high strength wastes a problem with treatment efficiency might be encountered. This could be offset by a reduction in hydraulic load which means that the mechanical shock to

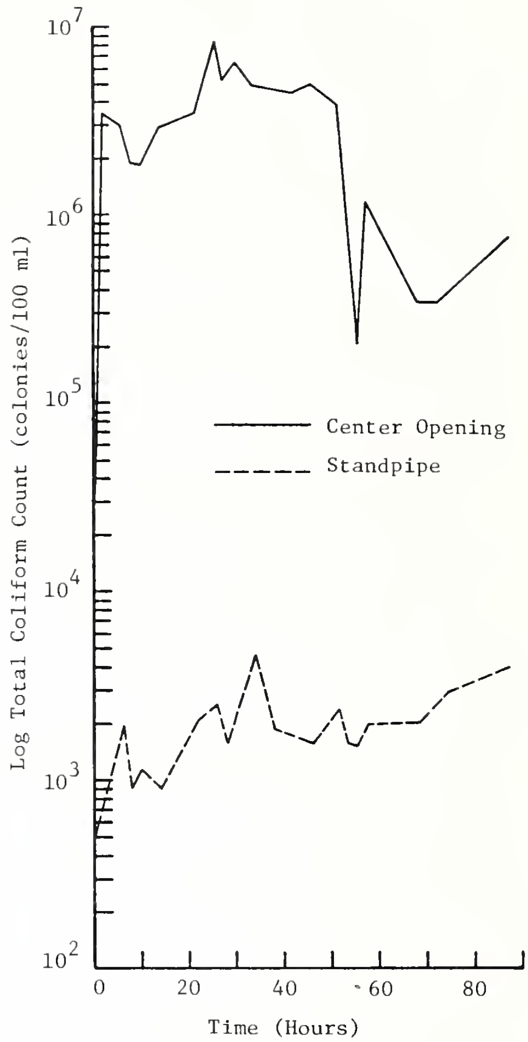


Figure 12. Diurnal Variations in Coliforms Under Second Dosage.

the system would be reduced.

In general, the ET units exhibit an acceptable degree of stability against shock loads but shows some response at the standpipes when moderate to high strength wastes are applied, or, as in the case of suspended solids, when a hydraulic shock is applied.

Aesthetics

Most people probably would not find an ET unit aesthetically objectionable. The center opening of the unit is at times unsightly due to algae growth and scum, but a perforated cover placed over this area would seem reasonable. Little or no odor has been detected from the ET unit. Hydrogen sulfide gas was observed under the shelter cover during the winter of 1974-75, however. At times, flies and mosquitoes are found on or near the center opening and in the tall grass on the unit. These insects could be considered a nuisance problem but were always few in number.

DESIGN OF THE EVAPOTRANSPIRATION UNIT

The sizing of an ET unit presented here is based on summer operation. Winter operation is believed to be minimal for cold climates until practical heating methods for the unit can be devised. The information for this section was the result of a Masters thesis by Glenn D. Lloyd, University of Wyoming, 1977, and a paper by Hasfurther, et al., 1977.

Evapotranspiration Determination

Estimation Methods

Sizing of an ET unit requires an estimate of the losses due to evapotranspiration. A review of the existing methods of estimating evapotranspiration (Jensen et al., 1973) resulted in selection of three generally accepted methods--the Blaney-Criddle, Jensen-Haise, and Penman methods, all of which use a range of variables that affect evapotranspiration.

The Blaney-Criddle method is concerned primarily with temperature, and takes factors such as solar radiation, plant density, elevation, relative humidity, and wind speed into account only through empirical coefficients. The general equation is (Blaney and Criddle 1962):

$$U = K_t K_c T P/100$$

in which U = consumptive use (evapotranspiraton) in inches; K_t = temperature coefficient; K_c = weekly crop coefficient; T = mean weekly temperature in ^{o}F; and P = percentage of daytime hours. The evapotranspiration estimates by this method are on a weekly basis.

The Jensen-Haise method takes solar radiation, temperature, elevation and humidity into account. The general equation is (Jensen and Haise 1963):

$$ET = \frac{(T - T_x) \times R_s}{[C_1 + (C_2 \times CH)]}$$

where ET = consumptive use in inches; T = mean weekly temperature; R_s = mean solar radiation in langleys; C_1 = empirical constant equal to 68-3.6 times the elevation above mean sea level divided by 100 feet; C_2 = constant of 13.2; CH = humidity index which is 50 millibars divided by the difference $E_2 - E_1$, where E_2 equals the saturation vapor pressure in millibars (mb) for mean maximum temperature for the hottest month of the year and E_1 equals the saturation vapor pressure in millibars (mb) for the mean minimum temperature for the hottest month; and T_x = temperature intercept which equals 27.5 ^{o}F - .25 $(E_2 - E_1)$ ^{o}F/mb - elevation above mean sea level in feet/1000 feet ^{o}F. Evapotranspiration estimates by this method can be done on a daily as well as on a weekly basis.

The Penman method uses solar radiation, wind speed, temperature and humidity. The general form of this equation is (Jensen et al. 1973):

$$E_{tg} = \left(\frac{\Delta}{\Delta + Y}\right)(Rn + G) + \left(\frac{Y}{\Delta + Y}\right) *$$

$$15.36\ (1.0 + .0062U_2)(E_z^{\ o} - E_z)$$

in which E_{tg} = consumptive use in inches; $\Delta/(\Delta + Y)$ = weighing parameter for temperature and elevation: $Y/(Y + \Delta) = 1 - [\Delta/(\Delta + Y)]$; Rn = net radiation (see below); G = solar heat flux; U_2 = wind speed factor = W x $(2.0/H)^{0.2}$ where W = wind speed in miles per day and H = height of gage in meters; and $E_z^{\ o} - E_z$ = vapor saturation deficit $(E_1 + E_2)/2 - E_3$ where E_3 = saturation vapor pressure in millibars for mean air temperature. The net radiation is determined by the equation

$$R_n = (1 - \alpha)R_s - (a\ R_s/R_{so} + b)\ \varepsilon'\sigma T^4$$

in which R_s = measured solar radiation in langleys; α = constant between .21 and .25 (.23); and a and b = regional constants (1.22 and -.18); R_{so} = clear day solar radiation; $\varepsilon'\sigma T^4$ = net outgoing long wave radiation in langleys. Solar heat flux is given by the equation

$$G = (T_{w-1} - T_{w+1})/14 + 51.43$$

in which T_{w-1} is the mean air temperature of the week prior in ^{o}F and T_{w+1} is the mean air temperature of the week following. The evapotranspiration estimates by this method are on a weekly basis.

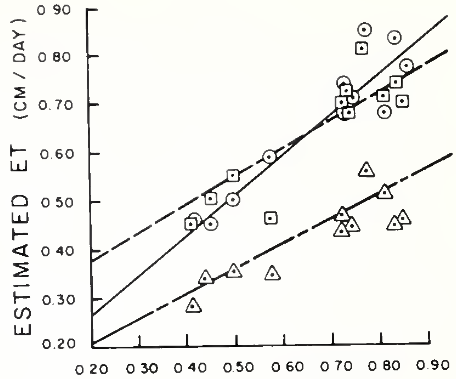
For all three methods of estimating evapotranspiration, the coefficients in the equations were obtained from tables, charts or graphs in Jensen et al. (1973), Swartz et al. (1972), and unpublished values from studies conducted by the Agricultural Engineering Department at the University of Wyoming. A meteorological station maintained by the Water Resources Research Institute at the University of Wyoming is located adjacent to the site of the ET unit. The meteorological data from this station (air temperature, wind speed, precipitation and relative humidity) and solar radiation data obtained on the University of Wyoming campus were used in the equations for the three methods to obtain estimates for evapotranspiration from the ET unit.

Comparison of Methods to Actual ET

Three years of data (Table 1) were available for comparison (1973, 1974 and 1975) of actual ET to the estimated ET values obtained by the three evapotranspiration methods. Only the results of the summer 1975 data will be shown, but the other two years will be discussed where differences were significant.

A linear regression was run between actual and estimated ET using weekly values for comparison purposes; the slope and intercept were determined, standard deviation computed, and the correlation coefficient obtained. Figure 13 shows the results for summer 1975 for all three methods. All three methods correlated to an acceptable degree; above 70 percent is considered good by most experts (Jensen et al. 1973). The Blaney-Criddle method gave the best overall results; the Penman method had a poor correlation in 1974 compared to 1975.

A separate analysis was made of the sum of the actual ET divided by the sum of the estimated ET for each method for the period of record used in 1975. The Blaney-Criddle method gave a value of 1.021; the Jensen-Haise method a value of 1.062; and the Penman method a value of 1.593. A value of 1.000 would mean that the estimation method exactly predicts the actual total ET. The 1974 data showed actual ET being about 10 percent less than estimated ET for the Blaney-Criddle and Jensen-Haise methods. The grasses on the ET unit were not as well established in 1974 as in 1975, which could partly explain the differences between the two years. In both 1974 and 1975, the Penman method produced consistently low results compared to the actual. The Penman method allows for the calibration of various constants within it. Due to the limited data base and because research on these constants



Mean Actual Evapotranspiration = 0.676 cm/day

Method	Symbol	% Correlation	St. Dev.
Blaney-Criddle	⊙ ———	90.6	.057
Jensen-Haise	⊡ – – – –	75.3	.051
Penman	△ — – —	83.1	.108

Figure 13. Estimated Weekly ET Versus Actual Weekly ET for 1975.

is presently being done for Laramie, it was found that if a single factor is applied to the Penman equation, the ratio of actual to estimated values can be brought close to 1.000. As a result, all three methods are capable of predicting water movement from the ET unit both on a weekly basis and over the summer season.

A comparison was also made between estimated average weekly ET values and actual ET for 1975. Assuming that the climatological values used in the estimation methods (solar radiation, temperature, etc.) do not change significantly from year to year for the same weekly period, average weekly climatological values were obtained using an 8-year data base (1968-1975). The average weekly values were then used to estimate average weekly ET rates. A comparison of these estimated average ET values to actual weekly ET values for 1975 gave correlations similar to those obtained by using the actual weekly climatological values for 1975. The analysis thus indicated that the ET rate on a weekly and seasonal basis remains reasonably constant from year to year. This is important because then an ET unit for a given area can be sized and expected to remove approximately the same amount of water year by year.

Sizing An ET Unit

In sizing an ET unit by each of the three estimation methods, the estimated average ET rates on a weekly basis for a summer season (May 1 - October 1) were calculated using the

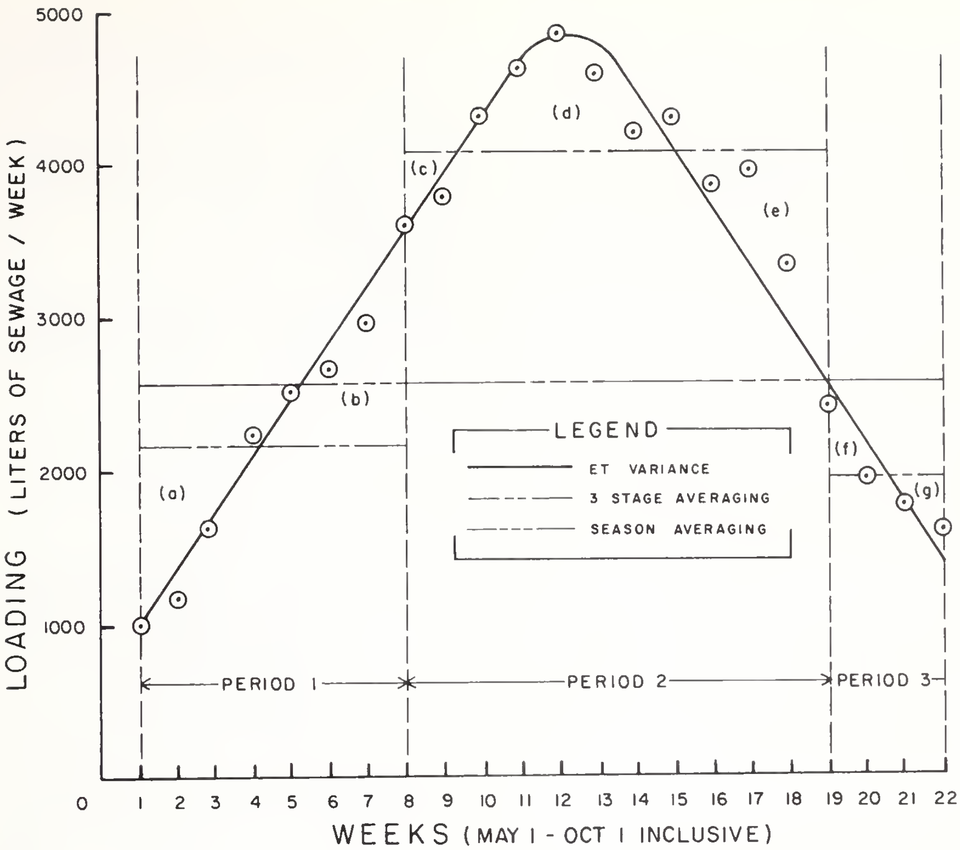


Figure 14. Blaney-Criddle Loading Curve With Different Loading Rates.

average weekly climatological values from 1968 to 1975.

Figure 14 presents the results for Blaney-Criddle which show that ET is continually changing from week to week. Since it is not realistic to expect the average user to vary his loading rate with the evapotranspiration occurring naturally, some method needs to be devised for storage to help average out the loading of the ET unit over periods of time. A method was thus devised for averaging the loading over time using the soil moisture available in the ET unit.

Seven basic steps are used in determining the loading of an ET unit by this method:

1. The ET curve (fig. 14) must have the average rainfall for the 8-year period over the same weekly period subtracted from it. The values generated can then be converted to the number of liters of wastewater that can be added to the unit per week (fig. 15).

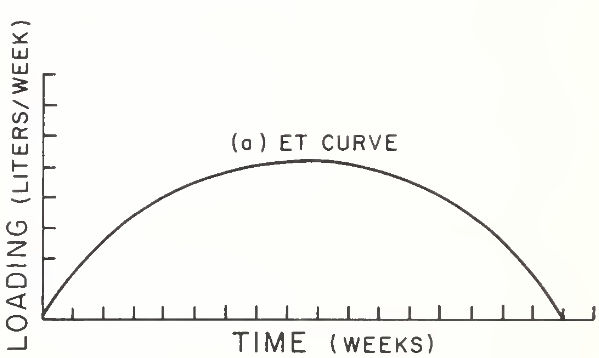


Figure 15. Evapotranspiration Curve Less Rainfall for Size Determination.

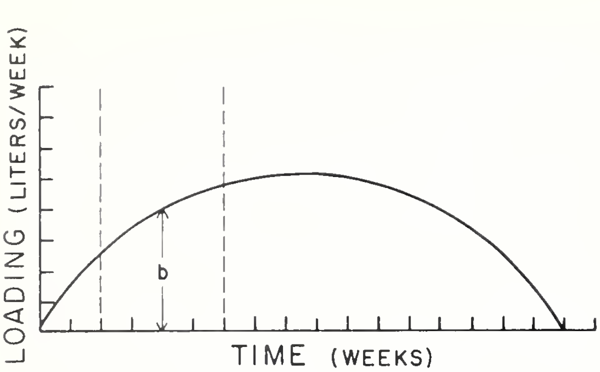


Figure 16. Period Selection for Size Determination.

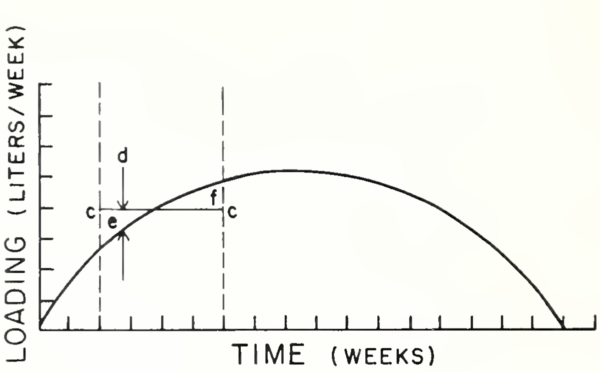


Figure 17. Average Loading and Storage Checking for Loading Rate Determination.

2. An ET unit has some storage capacity. A moisture holding capacity test on the constructed ET unit should be used to determine the average specific yield of the soil. It has been observed that within a range of 15.25 cm (based on the normal high and low fluid levels recorded), the fluctuation of water level does not significantly affect the ET rates from the grasses of an ET unit. Using these facts, an allowable amount of storage of wastewater in liters can be computed. The unit is assumed to be at a low level in May.

3. A period over which one would want to average the loading would be selected. For the present, an arbitrary period of 5 weeks is selected for illustrative purposes (fig. 16).

4. The loading amounts for the 5-week period chosen are summed and used to find an average loading. The average loading (line c-c of fig. 17) is superimposed on the ET estimation curve developed for the area (fig. 14).

5. The differences between the average line (c-c of fig. 17) and the ET curve in the area of (e) are summed. This number represents the number of liters which must be stored within the unit and is compared to the available storage obtained from Step 2.

6. If the difference between that needed and the amount available for storage is more than some small number near zero, then the average loading value (line c-c of fig. 17) should be adjusted.

7. This process is repeated for all of the different periods selected during the summer months.

It should be pointed out that area (f) of fig. 17 will always equal or exceed area (e). This means that the unit will always have its entire storage available (15.25 cm) at the end of any selected period.

To illustrate this method, a 111 m^2 unit will be sized for loading at Laramie, Wyoming, using the Blaney-Criddle estimation method. Figure 14 shows the loading curve to be used (solid line) with the average weekly precipitation already removed. The storage capacity for a change of 15.25 cm for a 111 m^2 unit with a specific yield of 24.08 percent is 4.08 m^3 (4080 liters). Following steps 5, 6 and 7 with the 4080 liters available for storage, an average loading rate for the entire summer period was found to be 2530 liters per week (fig. 14 shows the value).

Using the Jensen-Haise and Penman methods, the average loading rates for the unit were found to be 2940 liters per week and 2670 liters per week, respectively. Based on these results, a 111 m^2 unit should be able to handle 2600 liters of wastewater per week at Laramie, Wyoming.

Another period of design will also be considered. It must be recognized that a recreation home for a family with school-aged children may show a use variance based on when school is in season. To this end, an analysis of loading was made for three periods: (a) that part of the summer when young people are still in school and only weekend use is anticipated, (b) a period during summer recess (a more intense use period), and (c) a later summer period when school has resumed and only weekend use is again occurring. The periods were broken down as follows: weeks 1-7 (1 May - 18 June), as low use; weeks 8-18 (19 June - 3 September) as high use; and weeks

19-32 (4 September - 1 October) as low use again. The values of loading obtained for these periods using the method described previously were 2120 liters/week, 4075 liters/week, and 1920 liters/week, respectively. Figure 14 shows these results graphically. From figure 14, the excess fluid introduced in part "a" is depleted in part "d". During section "c", the storage is filled or partially filled, but part "f" depletes the storage sufficiently to allow excess loading at "g". This leaves the unit filled or partially filled at the end of the season. Experience has shown that this fluid is depleted during the winter by evapotranspiration and sublimation.

It was found from comparison studies that the surface area of an ET unit is directly proportional to loading rate. As a result, the actual size of an ET unit for a particular family can be determined. A family interested in installing such a unit would first need to determine the type of loading period that would fit their plans, and then consult with a trained sanitary engineer who could estimate their waste production. The following equation can then be used to size a family unit:

$$A = \frac{D \times P \times S \times 111}{L_{R111}}$$

where A = square meters of surface area for ET unit; D = days of use per week; P = number of persons in the family; S = liters per day of wastewater produced per person; and L_{R111} = loading rate in liters per week for the 111 m^2 experimental unit. For example, given a family of four persons, a wastewater loading rate of 190 liters per person per day, use of the unit for seven days per week and an assumed loading rate of 2600 liters per week; a 227 m^2 unit would be required.

It has been shown that a unit can be sized rather effectively for the Laramie, Wyoming area. By analogy, then, units can be sized for other areas. Factors that should be considered when estimating ET for sizing are: 1) select a method that has proven successful in estimating ET from grasses native for that particular area, and 2) make sure that the climatological data for the particular ET estimation method is available.

COST COMPARISON

One of the most important tests of feasibility for any wastewater treatment unit is its cost versus other alternatives. The alternatives to this unit are no treatment, septic tank with leach field, or some small package units. All comparisons of costs are made for installation in the immediate area of Laramie, Wyoming. Table 3 summarizes cost for various alternatives. Both the Nyodak and Septic Tank systems allow for the pollution of groundwater. The Armon system works like the proposed ET unit, but the cost of the ET unit studied in this paper will generally be less because of an expensive holding tank required by the Armon system. It is apparent from Table 3 that the ET unit is competitive with similar units presently on the market. The ET unit should be non-polluting, and should work in areas of high precipitation if it is covered with a transparent shield to prevent overloading.

Table 3. Cost comparisons

Type of Unit	Cost range ($)
Nyodak "Aerobic Treatment Unit"	2200 - 2500
Septic tank and leach field[1]	1300 - 1500
Armon system (ET with storage)	1800 - 3500 (2750 avg)
Proposed ET unit	1450 - 3200

[1] Includes cost of leaching field needed by these systems

CONCLUSIONS

The use of evapotranspiration for treating wastewater from rural and mountain second homes during the warmer months of the year has been shown to be feasible. While efficiency of the ET unit is markedly decreased during the colder months, summer operation is both effective and capable of handling the fluctuating loads typical of rural and mountain second homes.

The treatment of the actual wastewater by chemical and biological action in the ET unit are high but may not be completely within EPA standards for some uses of the water. It has been determined, however, that the ET unit is fairly insensitive to hydraulic and organic shock loads in terms of BOD, dissolved and suspended solids, and coliforms. Salts build-up in the unit has been insignificant and winter rest periods reduce both the dissolved and suspended solids.

ET units can be sized for loading during summer operation by use of evapotranspiration estimation methods. Different schemes were analyzed for loading the unit with the use of storage in the soil voids and allowable loading rates obtained.

The ET unit is cost competitive with more conventional units, provides zero ground and surface water pollution and is readily adaptable to most rural and mountainous areas.

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